Efficacy of combined radiofrequency ablation with distal ethanol infusion in the vein of Marshall for incomplete anterior mitral line in atrial tachycardia

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Introduction

The presence of low-voltage areas (LVAs) or scars in the left atrial anterior wall is a significant arrhythmogenic substrate for atrial fibrillation (AF) and atrial tachycardia (AT).[1,2] The anterior mitral line (AML) is one of the effective methods for modifying and treating AF and AT[3,4]; however, this linear ablation can occasionally create iatrogenic reentrant substrates for complex AT.[5] Performing a linear ablation at the mitral isthmus (MI) following AML carries a substantial risk of electrical isolation of the left atrial appendage (LAA). This case report presents a perimitral AT (PMAT) via the Marshall bundle (MB) that developed following an incomplete AML deployment. We successfully terminated the PMAT, sparing MI conduction through distal ethanol infusion into the vein of Marshall (VOM), and achieved a complete conduction block at the AML.

KEY TEACHING POINTS

- Impaired electrical activity in the anterior left atrium can serve as a substrate for arrhythmias. Using the anterior mitral line (AML) presents a viable strategy for managing atrial fibrillation (AF) and atrial tachycardia (AT). However, achieving a complete conduction block along the AML poses a notable challenge due to the intricate anatomical features of the region.
- In case where the conduction block along the AML is incomplete, there is a risk of inducing complex AT, wherein epicardial conduction plays a significant role.
- The Marshall bundle, characterized by its anatomical variability among individuals, may have its distal end located near the AML in certain cases. Following an incomplete conduction block at the AML, employing a combination of ethanol infusion into the distal vein of Marshall alongside conventional radiofrequency ablation emerges as a promising alternative for achieving a complete conduction block at the AML while preserving conduction integrity at the mitral isthmus.

Case report

An 80-year-old woman presented with recurrent palpitations. Electrocardiography (ECG) showed narrow QRS tachycardia, which was not responsive to adenosine triphosphate administration (20 mg). We conducted an electrophysiological study and high-resolution mapping using the Rhythmia system (Boston Scientific, Marlborough, MA) with a mini-basket catheter (Orion, Boston Scientific, Marlborough, MA). During distal coronary sinus (CS) pacing, the high-resolution map revealed low-voltage areas in the anterior left atrium (LA) and MI, along with scarring in the anterior LA (Figure 1A). Rapid atrial pacing induced an AT (AT1) with a tachycardia cycle length (TCL) of 320 ms. The high-resolution activation map demonstrated a dual-loop AT consisting of clockwise PMAT and scar-related localized AT, both sharing a common isthmus at the anterior LA (Figure 1B). However, AT1 incidentally terminated during entrainment pacing. Therefore, we designed an AML across the scar at the anterior LA using an ablation catheter (Stablepoint, Boston Scientific, Marlborough, MA) delivering 40 W for 30 seconds at each point after pulmonary vein isolation. Post-AML deployment, the ECG P-wave to LAA time was delayed, and intra-ECG at the LAA changed compared with before and after AML ablation (Figure 2A). Following incidental catheter stimulation, a second AT (AT2) with a TCL of 280 ms was induced

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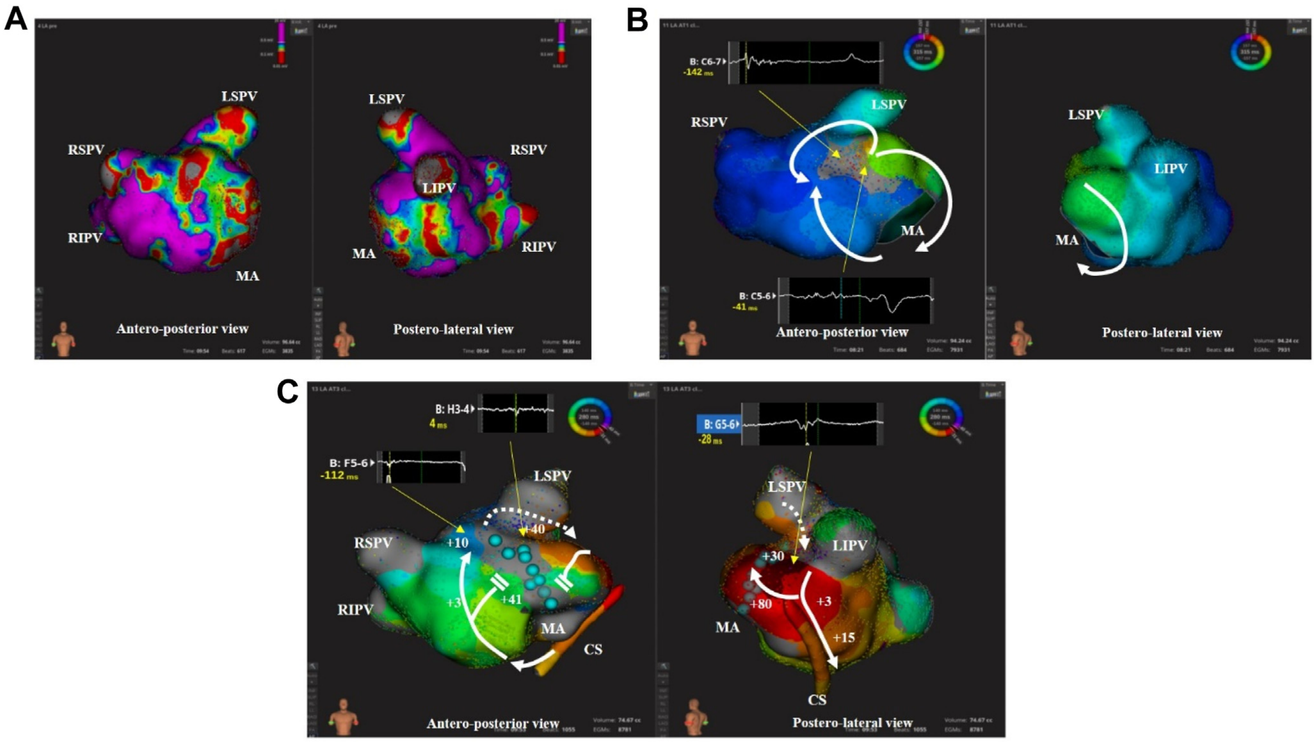

Figure 1 **A:** Bipolar voltage map during pacing at the distal coronary sinus shows low voltage areas in the anterior LA and MI and a scar in the anterior LA. Low-voltage areas and scars are defined as <0.5mV and <0.1mV, respectively. **B:** High-resolution isochronal activation map during AT1 with a TCL of 320 ms indicates a dual-loop AT comprising a clockwise perimitral AT (PMAT) and a scar-related AT. Fragmented potentials with long duration are present in the scar at the anterior LA. Each color between red and purple represents a 20 ms activation time. The confidence mask is set at <0.03mV. *White arrows* show endocardial propagation. **C:** High-resolution isochronal map during AT2 with a TCL of 320 ms demonstrates a clockwise PMAT across the anterior mitral line after radiofrequency ablation, indicated by the blue tags. The numbers at each point on the maps indicate the value of the post-pacing interval minus the TCL (ms) during entrainment pacing. Each color between red and purple represents a 20-ms activation time. The confidence mask is set at <0.03 mV. *White arrows* and *double lines* represent endocardial activation propagation and conduction block, respectively. *White dotted arrows* indicate possible epicardial propagation. AT = atrial tachycardia; CS = coronary sinus; MA = mitral annulus; MI = mitral isthmus; LA = left atrium; LIPV = left inferior pulmonary vein; LSPV = left superior pulmonary vein; PMAT = perimitral atrial tachycardia; RIPV = right inferior pulmonary vein; RSPV = right superior pulmonary vein; TCL = tachycardia cycle length.

after AML ablation and the activation pattern was centrifugal activation from lower LA ridge.[6] The activation map of AT2 and the results of entrainment pacing from various points demonstrated a clockwise PMAT across the AML (Figure 1C). Activation wavefronts collided between the AML, indicating a conduction block on the endocardial surface, though epicardial conduction remained at the AML near the upper LA ridge. The involvement of the MB was considered because of the activation propagation traveling across the AML and emerging from the lower LA ridge with an activation gap between the AML and lower LA ridge. A 0.014-inch guidewire (Runthrough Ph, Terumo, Tokyo, Japan) was inserted into the VOM, and we successfully recorded the unipolar potential in the VOM,[7] which preceded the bipolar potential at the distal CS and the unipolar potential could compensate activation gap between the medial side of the AML and lower LA ridge (Figure 2B). Concerned about electrical isolation of the LAA when creating a conduction block at the MI, we performed distal ethanol infusion into the VOM to spare MI conduction. The anatomic position of the mitral annulus was angiographically and 3-dimentionally marked, and an angioplasty balloon (Emerge, Boston Scientific, Maple Grove, MN) was advanced to the distal VOM for the infusion of 3.0 mL of 98% ethanol (Figure 2C). This procedure successfully terminated AT2, with a marked delay in the ECG P-wave to LAA time (Figure 2A). We attempted to advance the guidewire to the distal VOM again to confirm the presence of any residual electrical potentials, but the attempt was unsuccessful. The voltage map and conduction velocity along the MI with the isochronal activation map exhibited only slight changes pre- and post-ethanol infusion (Figure 3A and 3B), verifying the presence of a conduction block at the AML from LAA pacing. The electrical sequence between LAA and distal CS also did not change pre- and post-ethanol infusion (Figure 3C). Subsequently, electrical conduction along the MI was spared, conduction block at the medial side of AML was also confirmed (Figure 3D), and no further ATs could be induced by any atrial pacing.

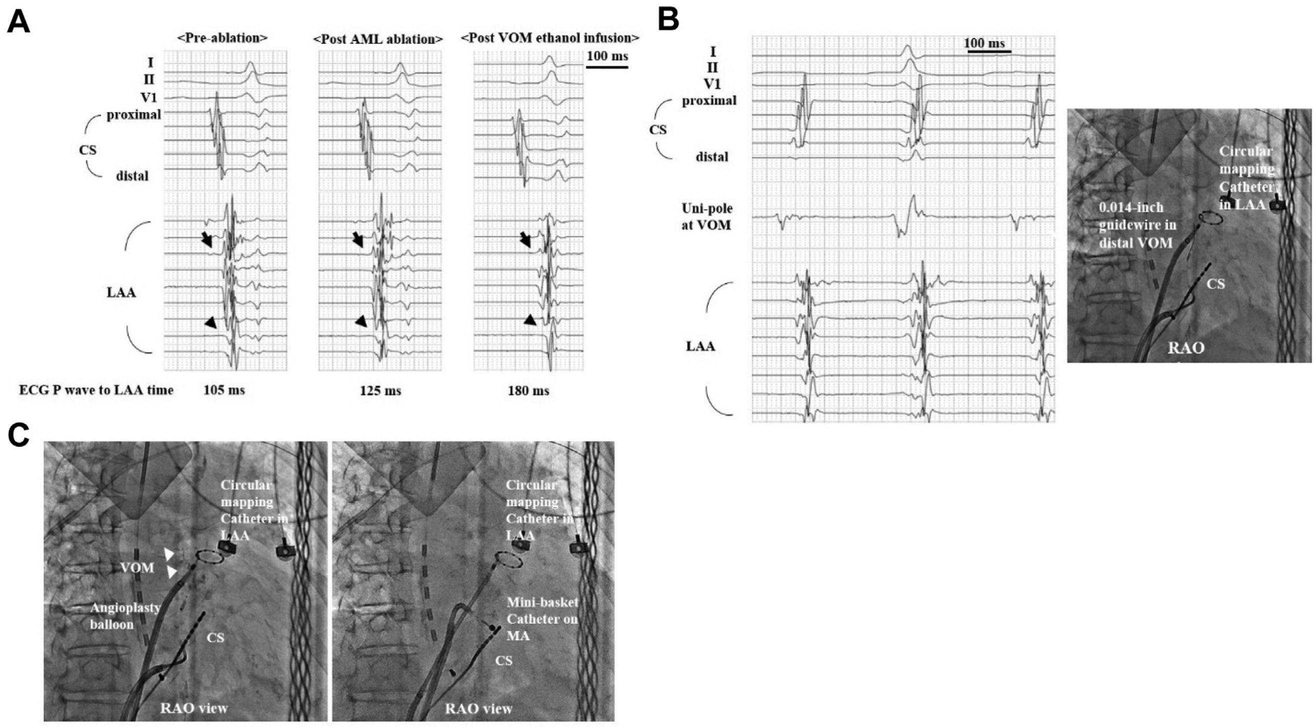

Figure 2 **A:** Intra-electrocardiogram showing the relationship between ECG P-wave and left atrial appendage (LAA) time in three states: pre-radiofrequency ablation (left panel), post-radiofrequency ablation at the anterior mitral line (center panel), and post-ethanol infusion (right panel). A decapolar circular catheter (Libero SG, Lifeline, Tokyo, Japan) was placed in the same position in the LAA. *Black arrow heads* indicate farthest electrodes from the anterior mitral line and black arrows show the closest electrodes from the line. **B:** Intra-electrocardiogram (*left panel*) during AT2 showing the unipolar potential at the vein of Marshall (VOM) with a 0.014-inch guidewire. The fluoroscopic image (*right panel*) shows the 0.014-inch guidewire inserted into the distal VOM. **C:** Fluoroscopic image (*left panel*) showing the angioplasty balloon occluded in the distal VOM during ethanol infusion in AT2. The *right panel* shows a mini-basket catheter placed at the mitral annulus as a marker. AML = anterior mitral line; AT = atrial tachycardia; CS = coronary sinus; ECG = electrocardiogram; RAO = right anterior oblique; MA = mitral annulus; VOM = vein of Marshall.

Discussion

This case report demonstrates the utility of distal ethanol infusion into the VOM to complete the conduction block of the AML after radiofrequency ablation. The combination of radiofrequency ablation and ethanol infusion into the VOM, particularly wedging the distal VOM to spare MI conduction, presents an alternative method for achieving complete AML in challenging cases.

Deploying the AML in the presence of LVA or scarring at the anterior LA is a feasible method for preventing AT/AF recurrence.[3] However, achieving a complete AML is challenging because of the anatomic complexity of the anterior LA.[8,9] Epicardial connections, such as Bachmann' bundle, can result in incomplete conduction block when designing the AML with radiofrequency ablation from endocardium in some cases,[5,10] particularly with the existence of fibrosis.[11] In our case, the existence of LVA and scar likely contributed to the incomplete conduction block along the AML during radiofrequency application, as we could not deliver sufficient thermal effect to the epicardial surface.

The reentrant circuit of AT2 involved the MB, as evidenced by the guidewire mapping and response to ethanol infusion into the VOM. The MB has multiple connections and epicardial anatomical variations.[12] In our case, the VOM ran along the LA ridge, and the distal VOM reached the upper LA ridge near the AML, where AT2's activation propagation traveled across. Ethanol infusion into the distal VOM near the AML affected both the AT2 circuit and the epicardial conduction block at the AML. Designing a conduction block at the MI after incomplete AML ablation risks electrical isolation of the LAA. Distal VOM occlusion during ethanol infusion is a useful technique to spare MI conduction.[13]

Conclusion

Our case successfully demonstrated achieving a complete AML with a combination of radiofrequency ablation and distal ethanol infusion into the VOM while sparing MI conduction. This case highlights a potential alternative approach for deploying a complete conduction block with AML and underscores the need for further investigation into the safety and efficacy of this method.

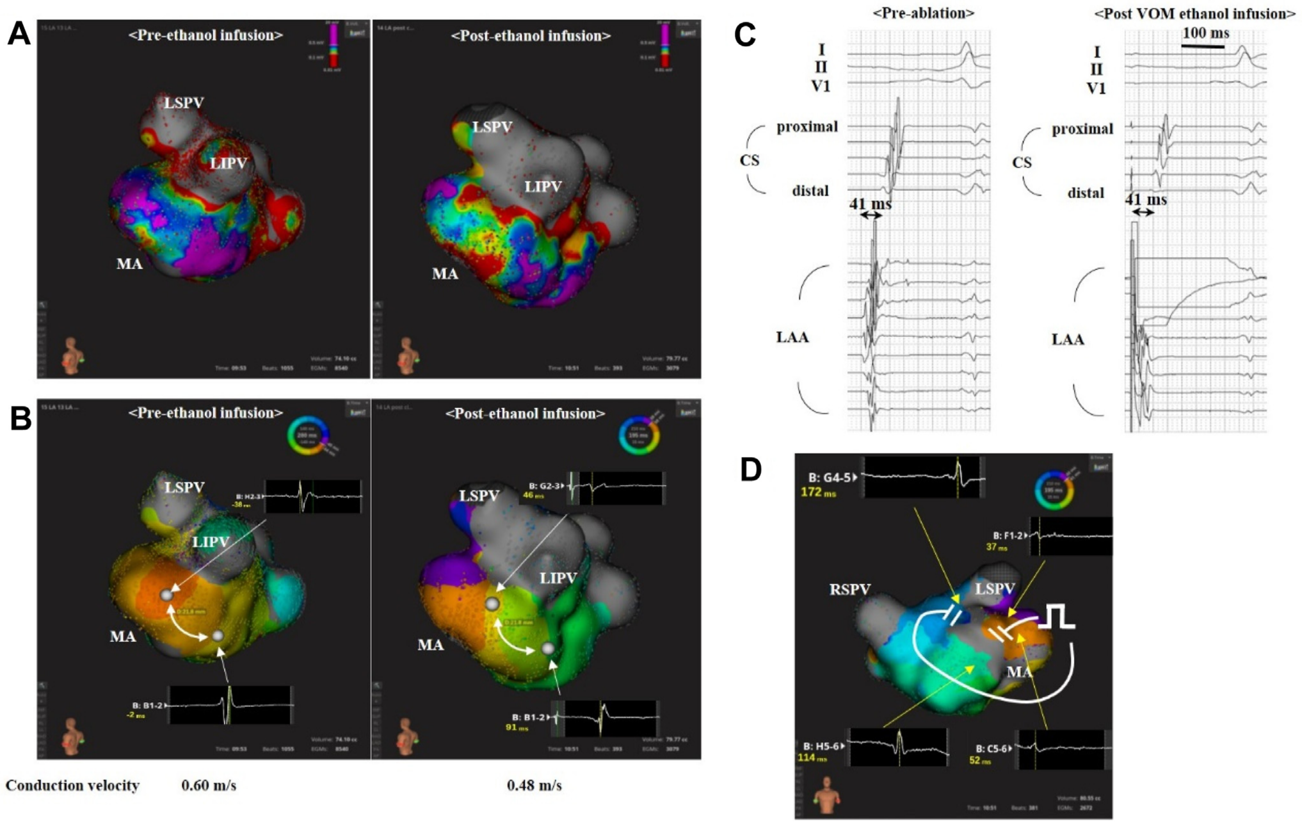

Figure 3 **A:** Bipolar voltage maps during AT2 (left panel) and pacing at the left atrial appendage (*right panel*). Following ethanol infusion therapy to the VOM, a slight spread of low-voltage area at the MI was observed compared to pre- and post-ethanol infusion states; however, no marked impairment of atrial tissue was evident. Low voltage areas and scar were defined as <0.5mV and <0.1mV, respectively. **B:** Isochronal activation map during AT2 before ethanol infusion to VOM (*left panel*) and pacing at LAA after ethanol infusion to VOM (*right panel*). The distance between the white tags (*white bidirectional arrow*) on each map is consistent at 21.8 mm. Mean conduction velocity between the white tags before and after ethanol infusion to VOM is 0.60 m/s and 0.48 m/s, respectively, demonstrating conduction sparing at MI after ethanol therapy. Each color between red and purple represents a 20-ms activation time. The confidence mask of the map is set at <0.03 mV. **C:** Intra-electrocardiograms recorded before (*left panel*) and after (*right panel*) the ethanol infusion demonstrate the same activation sequence at the CS. The conduction time from the LAA to the distal CS, indicated by the black bidirectional arrow, remained unchanged between the two recordings. The *left panel* depicts a paroxysmal atrial beat originating from the LAA, while the right panel shows pacing from the LAA. **D:** Isochronal activation mapping during pacing at the LAA after ethanol infusion into the VOM revealed that the activation wavefront on the medial side of the AML traveled around the MA rather than across from the lateral to medial side of the line. *White arrows* and *double lines* indicate endocardial activation propagation and conduction block, respectively. Each color gradient between red and purple represents a 20-ms activation time interval. AT = atrial tachycardia; CS = coronary sinus; LAA = left atrial appendage; LIPV = left inferior pulmonary vein; LSPV = left superior pulmonary vein; MA = mitral annulus; MI = mitral isthmus; VOM = vein of Marshall.

Ethics Statement: The procedure and management were conducted following the ethical guidelines of the Declaration of Helsinki. Written informed consent was obtained from the patient.

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